Arrays for Use at the Cobalt Irradiation Facility

Technical Report 97-2

$$\mathbf{RSD}^2 = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix}$$

Armed Forces Radiobiology Research Institute

September 1997

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Foreword

This report is a compendium describing the characterization of current arrays used to hold and position objects for irradiation in the AFRRI ^{60}Co irradiation facility. The arrays are specifically designed for use with nonhuman primates, canines, ferrets, guinea pigs, rats, mice, spores, cells, and chemicals.

These arrays have been characterized and approved by the Operational Dosimetry Division of the Radiation Sciences Department. The use of the standardized arrays is encouraged because their dosimetry characteristics, such as dose conversion factors and field uniformity, have been determined for each array. Various potential dosimetry measurement problems—scattered radiation and unwanted electron production within the array—have also been studied.

Researchers wishing to use the ^{60}Co facility are encouraged to contact the division on the use of an existing standard array. We are also most willing to work with an experimentalist in developing a new array or modifying an old array to meet a particular need.

This compendium draws on the history and the vast corporate knowledge of present and past members of the Operational Dosimetry Division. Special thanks are due to Arthur Webb who suggested the recharacterization of the arrays.

Henry M. Gerstenberg
Chief, Operational Dosimetry Division

Contents

Introduction

This report is a compilation of experimental irradiation arrays designed for use in the AFRRI cobalt-60 gamma irradiation facility. Each of these arrays (in conjunction with appropriate phantoms) have been characterized in terms of dosimetry quantities of interest by the Operational Dosimetry Division of the Radiation Sciences Department (RSD). The quantities of interest are the dose conversion factor (DCF, defined as the ratio of the tissue dose-rate measured at a given point in a phantom within the irradiation array to the tissue dose-rate measured at a standard position free-in-air, in the absence of the array) and the uniformity of the radiation field at the irradiation position. The currently approved arrays include arrays for the irradiation of mice, rats, ferrets, guinea pigs, canines, nonhuman primates, biological spores and cells, and a number of chemical solutions. The individual arrays are described in detail.

Design Considerations

There are a number of concerns when designing and characterizing an irradiation array: absorption, scattering, and presence of extraneous electrons in the γ-ray field. The primary objective is the determination of a DCF and field uniformity. The value of using one of the arrays described in this report is that all these concerns have been satisfactorily addressed, thus minimizing the amount of dosimetry to be carried out by RSDD before an investigator can start experimental work in the cobalt facility.

Scattered Radiation

Incident radiation on any object may be scattered in another direction rather than being absorbed by the object. It is possible for radiation to scatter forward, which is simply to say that it has passed through whatever object that it was incident on.

Scattering has important effects on the design of the experimental array. A portion of the radiation incident on the array will be scattered into the rest of the array or out of the array entirely. For example, an object on the interior of an array receives scattered radiation from the other objects surrounding it, whereas an object on an outside edge will only receive array-scattered radiation from one or two directions, not from all directions. It is important to make sure that all objects in the array are in a uniform scattering environment. This is accomplished by placing phantoms on the periphery of an array, allowing for a uniform scattering environment for all experimental objects that are now in the interior of the array. The phantom interacts with the incident radiation in a manner similar to the actual objects being irradiated; the phantom can be acrylic, polystyrene, or a container filled with water or tissue-equivalent plastic.

Presence of Electrons

The interaction of the γ-rays from the ^{60}Co source with the cladding of the source-element rods, with the elevators, and with various other objects in the exposure causes electrons to be ejected into the irradiation facility. Unless appropriate precautions are taken, some of these extraneous electrons will be incident on the experiment being irradiated.

The presence of extraneous electrons in the ^{60}Co radiation field is of concern because electrons deposit their energy in a very different manner than photons. It is necessary to filter any electrons out of the radiation field incident on the experiment so that it is exposed to as pure a ^{60}Co radiation field as is practically possible. This is accomplished by enclosing the experiment in an acrylic shield of suitable thickness to absorb the energetic electrons from photoelectric and Compton interactions with material outside the array.

DCF and Field Uniformity

Ideally, the point used to determine the DCF is the center of the irradiation array. To determine field uniformity, measurements are taken at the top, bottom, and both ends of the array when appropriate and compared to the measurements taken at the center of the array. The ratio of the edge readings to the center readings is field uniformity.

Canine Array

Approved Array

Two canines in restraint boxes, tail-to-tail

Description

Two canines, placed in restraint boxes, are brought into the cobalt facility. The boxes are placed on the irradiation table, centered in the field, and irradiated bilaterally. The restraint boxes are used to ensure a certain degree of uniformity and reproducibility in irradiation geometry from subject to subject. The boxes are constructed of acrylic sheets thick enough to provide shielding from extraneous electrons. The head of the canine, which protrudes from the restraint box, is shielded from extraneous electrons from the sides facing the source rods.

Physical Considerations

Charged-particle equilibrium (CPE) concerns have been addressed in the design of the array itself. The restraint boxes have been designed to provide CPE.

If there is any deviation from the approved array, the change must be approved by RSDD to ensure that all physically significant issues are addressed and that the investigator's requirements are met.

DCF

Array	DCF
Two canines in restraint boxes, tail-to-tail	0.92

Reference

See Dosimetry Protocol C-93-01, Dosimetry for Dual Canine Irradiations (^{60}Co), for detailed information on two canines in restraint boxes in the tail-to-tail irradiation array.

Cell Arrays

Approved Arrays

One small petri dish with CPE cover (fig. 1)

Three small petri dishes in one large petri dish with CPE cover (fig. 2)

Plate (96-well) array (fig. 3)

Tube (15-ml) array (fig. 4)

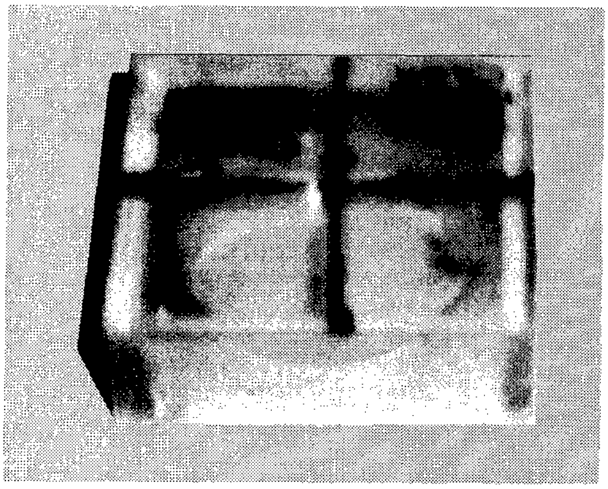

Fig. 1. One small petri dish with CPE cover.

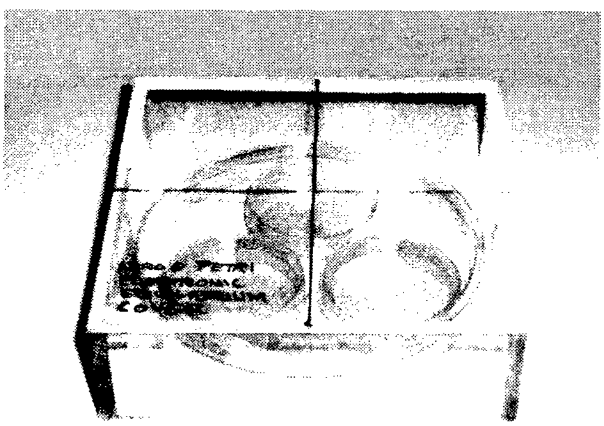

Fig. 2. Three small petri dishes in one large petri dish with CPE cover.

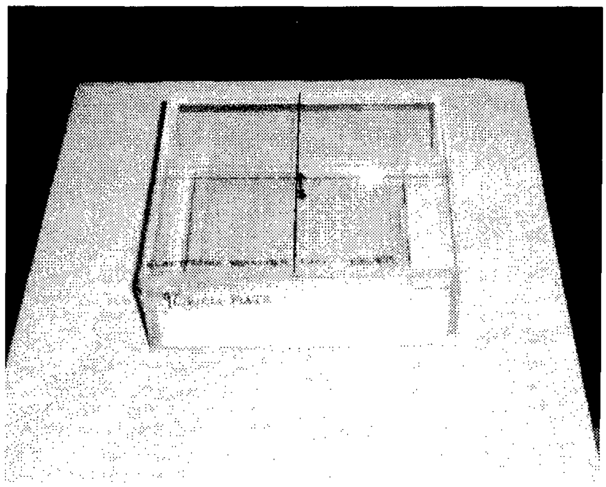

Fig. 3. Plate (96-well) with CPE cover.

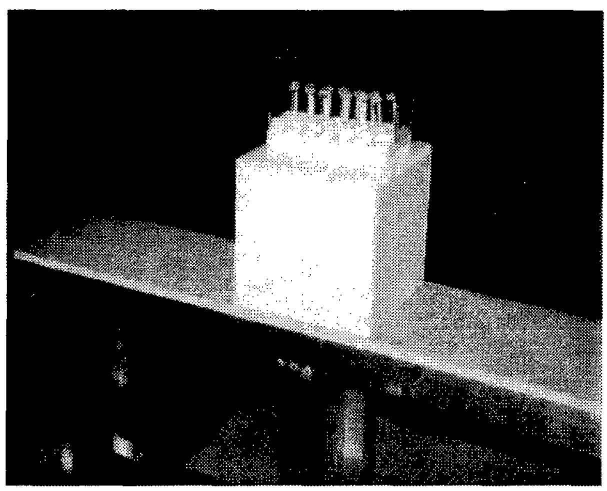

Fig. 4. Tube (15-ml) array.

Tube (50-ml) array (fig. 5)

Flask (50-ml) array (fig. 6)

Flask (450-ml) array (fig. 7)

Two-flask (450-ml each) array (fig. 8)

One small petri dish. One small petri dish is centered on the white support box that is used to raise all cell arrays off the experiment table in the cobalt facility. The CPE cover designed for this array is then placed over the petri dish. The sample is irradiated.

Three small petri dishes in one large petri dish. Three small petri dishes are placed in a large petri dish. If there are only two small petri dishes with cells, a third small petri dish filled with water to the same level as the level of the solution in the other two petri dishes must be placed into the large petri dish as a phantom. The large petri dish is then placed on the white support box and centered, and the appropriate CPE cover is placed over it. The sample is irradiated. A greater number of smaller petri dishes are also approved; the maximum possible number of petri dishes must always be placed in a large petri dish, with the dishes without cells serving as phantoms. The CPE cover must be used in all instances.

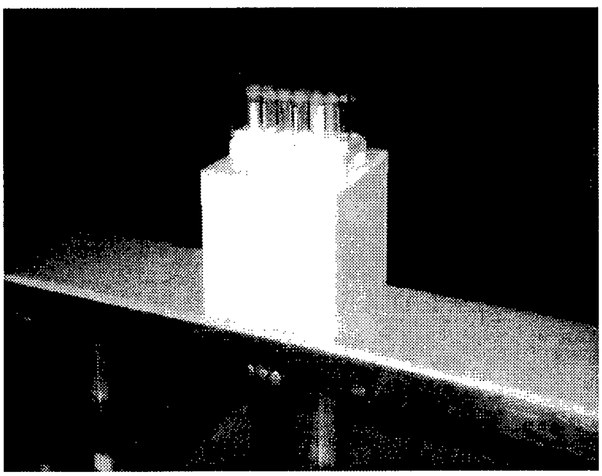

Fig. 5. Tube (50-ml) array.

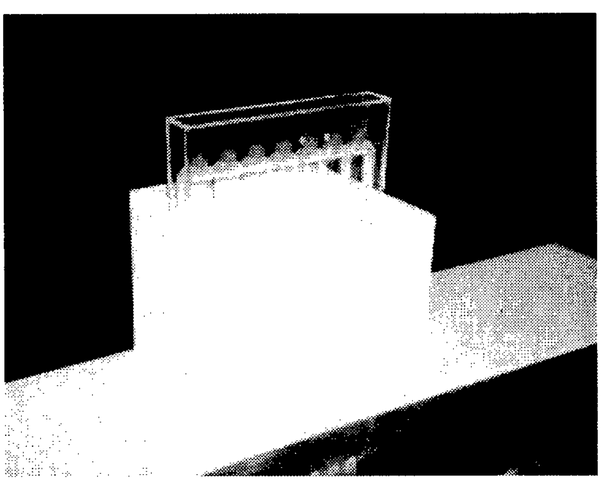

Fig. 6. Flask (50-ml) array.

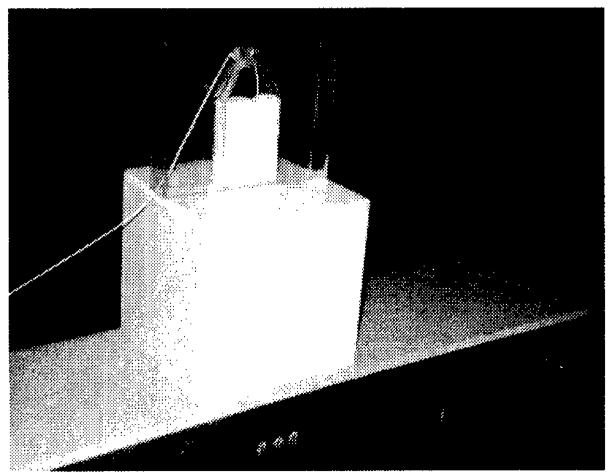

Fig. 7. Flask (450-ml) array.

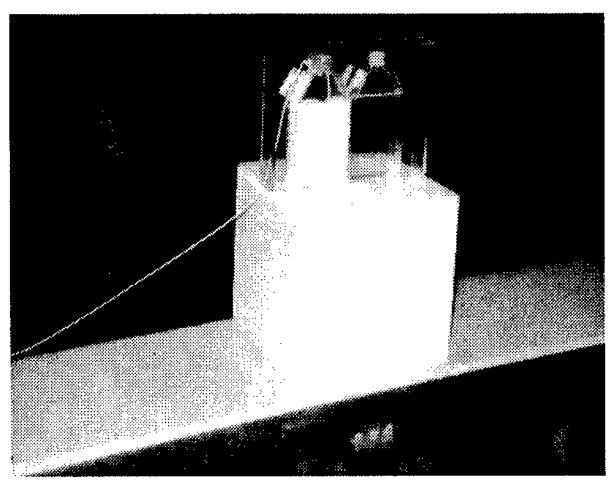

Fig. 8. Two-flask (450-ml each) cell array.

96-well plate. A 96-well plate is placed on the white support box and centered. The outermost row of wells is filled with tissue-equivalent (TE) plastic or water for uniform scattering. The appropriate CPE cover is then placed over the 96-well plate. The array is irradiated. The use of well plates with larger wells is also approved. In all cases, the outermost row of wells and any interior wells not filled with solution must be filled with TE plastic or water. The CPE cover must be used in all instances.

15-ml and 50-ml tube arrays. A tube array in a Styrofoam holder is placed on the white support box and centered. All positions on the raised portion of the holder are filled with tubes of appropriate size. The two outermost positions on each end and the interior positions without tubes must be phantoms. A phantom consists of a tube of the appropriate size filled with TE plastic or water to a level equal to the level of solution in the other tubes. Fill positions in the array from the center out. The appropriate CPE cover is placed over the array. The array is irradiated. The use of other tube sizes between 15 ml and 50 ml is also approved following the guidelines above.

450-ml flask arrays. One or two 450-ml flasks are placed on the white support box. A single flask is centered on the box. Two flasks are placed side by side across the field and centered on the box. For the two-flask array, both flasks must be filled with solution to equal levels. The appropriate CPE cover is then placed over the flasks, and the array is irradiated.

50-ml flask arrays. Seven flasks placed side by side are centered across the white support box, parallel to the field. The flask at each end of the array must be a phantom filled with TE plastic or water to a level equal to the level of solution in the other flasks. Only five flasks of cells can thus be irradiated at a time. The appropriate CPE cover is placed over the flasks. The array is irradiated. Fewer than five flasks can also be irradiated at a time. Place phantoms into the array where flasks of cells would otherwise be. Fill positions in the array from the center out.

Physical Considerations

Due to the nature of these arrays, acrylic CPE covers must be used. If samples are irradiated without satisfying the conditions of CPE, dosimetry cannot be considered reliable. Accordingly, CPE covers have been made to fit over each array. These covers must be placed over the array before irradiation to ensure accurate results.

It is very important that phantoms be used as prescribed above. They provide uniform scattering and therefore uniform doses throughout the arrays. If phantoms are not used at the ends of arrays, the doses to the samples on both ends of the arrays cannot be considered the same as the doses to the samples in the well-characterized portion of the array. If phantoms are not used within an array where appropriate, the dose throughout the array cannot be considered well-characterized.

If there is going to be any deviation from approved arrays, the deviation must be approved by RSDD to ensure that all physically significant issues are addressed and that the investigator gets the desired results.

DCFs and Field Uniformities

Array	DCF	Field uniformity
Single small petri dish	0.94	7%
3 small petri dishes in large petri dish	0.89	5%
96-well plate	0.94	5%
15-ml tubes	1.07	5%
50-ml tubes	1.07	5%
50-ml flasks	1.10	2%
Single 450-ml flask	1.07	5%
2 450-ml flasks	1.08	5%

Ferret Array

Approved Array

One ferret with head shielded (fig. 9)

Description

A lead cave is built to sufficiently shield the head of a ferret. The dimensions of this cave were determined through earlier dosimetry studies to achieve a specific degree of attenuation (Notebook BRP-18, p. 39). The cave specifics are 3 lead bricks on both sides of the ferret's head, 4 lead bricks at the end, and 2 lead bricks on top. The ferret, in a cylindrical holder, is then placed so that its head is inside the cave. The whole array, cave and ferret, is centered on the lines marked on the irradiation table and irradiated. If attenuation other than the attenuation provided below is desired, further dosimetry studies will be necessary to determine a new cave configuration. The setup for this array is provided in figure 9. Exact cave construction for the degree of attenuation is provided below.

Physical Consideration

CPE concerns have been addressed in the design of the array itself. The ferret holder provides CPE.

It is very important that the ferret holder is totally inside the cave and in contact with the lead wall to achieve proper attenuation of the γ-ray field. This

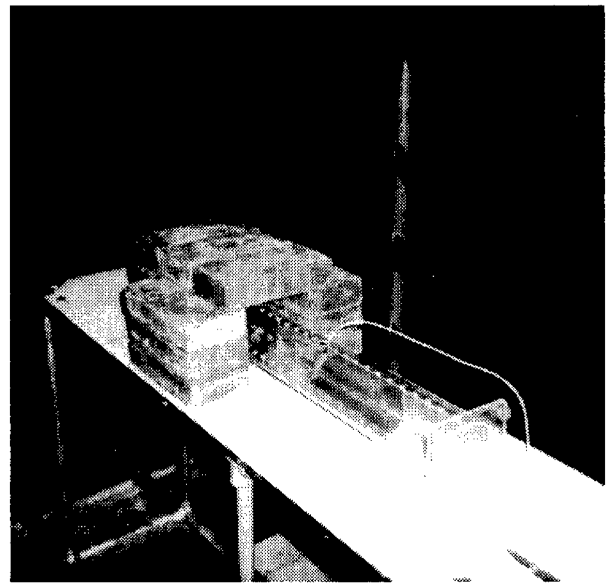

Fig. 9. Ferret with head shielded.

is done by pushing the holder into the cave until it contacts the lead wall and can go no farther.

If there is going to be any deviation from the approved array, it must be approved by RSDD to ensure that all physically significant issues are addressed and that the investigator gets the results desired.

DCF and Attenuation

Array	DCF	Attenuation
One ferret with head shielded	0.90	>97% to head

Guinea Pig Array

Approved Array

Six guinea pigs, whole-body bilateral exposure (fig. 10)

Description

Four racks are centered across the field. Each rack contains five tubes. The five tubes in the racks at both ends of the array are filled with phantoms. The top and bottom tubes in the two center racks are also filled with phantoms. The three middle tubes of the two center racks hold six guinea pigs. If any of these six tubes are not holding guinea pigs, they <u>must</u> be filled with phantoms.

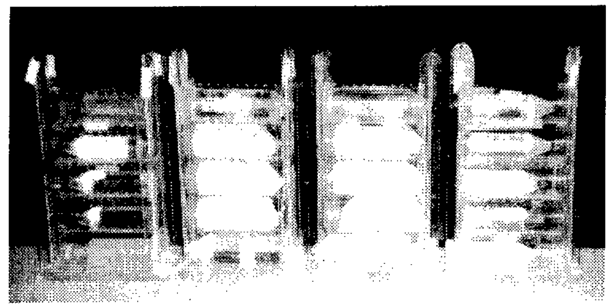

Fig. 10. Six guinea pigs, whole-body bilateral exposure.

If there is going to be any deviation from the approved array, it must be approved by RSDD to ensure that all physically significant issues are addressed and that the investigator gets the results desired.

Physical Consideration

If the investigator neglects to use phantoms to fill the gaps within the characterized portion of the array (when fewer than the maximum number of guinea pigs that each rack can hold is irradiated), the dose throughout the array cannot be considered to be well-characterized.

DCF and Field Uniformity

		Field uniformity	
Array	DCF	Vertical	Horizontal
Six guinea pigs, whole-body bilateral exposure	0.95	1%	2%

Mouse Arrays

Approved Arrays

One full single-load rack with phantom racks on both ends (fig. 11)

Two full single-load racks with phantom racks on both ends (fig. 12)

Three full single-load racks with phantom racks on both ends (fig. 13)

One single-load mouse box on white support box (fig. 14)

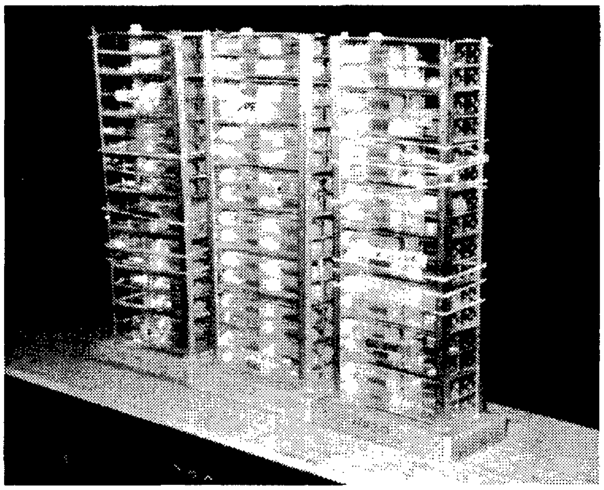

Fig. 11. One full single-load rack with phantom racks on both ends.

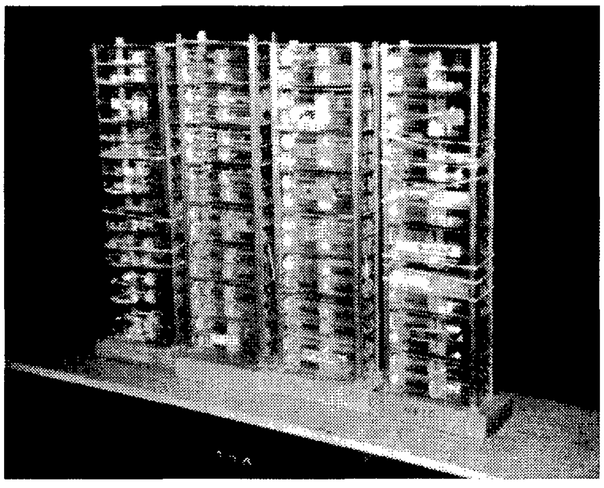

Fig. 12. Two full single-load racks with phantom racks on both ends.

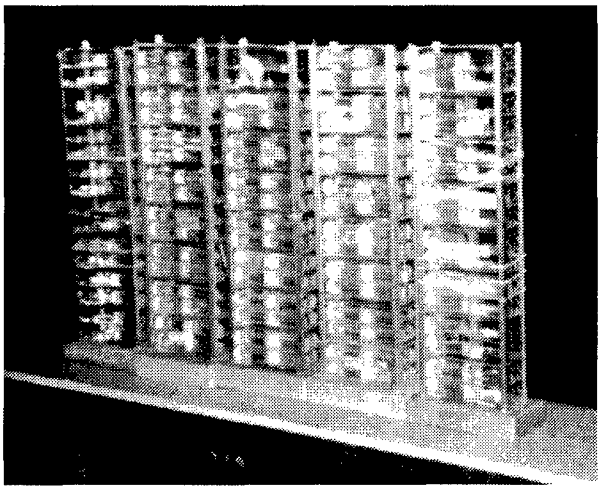

Fig. 13. Three full single-load racks with phantom racks on both ends.

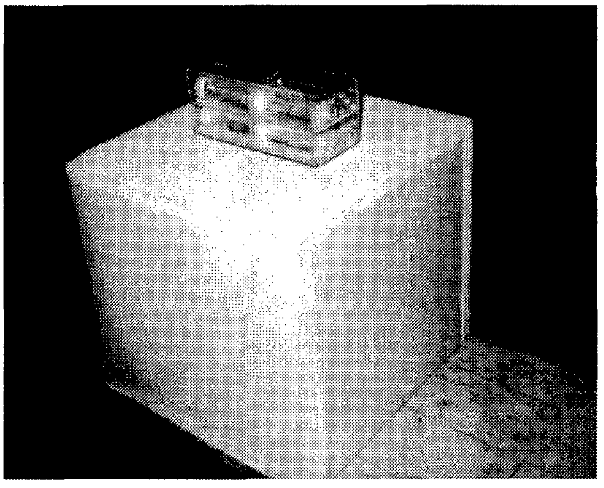

Fig. 14. One single-load mouse box on white support box.

Two single-load mouse boxes on white support box (fig. 15)

Description

The setup for each of the rack arrays is almost identical; the only difference is the number of full or single-load racks of mice to be irradiated. Each mouse box has four positions to hold mice; in a full load the four positions in a mouse box are filled, whereas in a single load only two positions on one side of the mouse box are filled. The general setup consists of the desired number of full racks with extra racks on both ends. The racks on both ends must be filled to capacity with mouse boxes, and the halves of the boxes that are next to a full rack must also contain mouse phantoms (fig. 11). Each full rack must also be filled to capacity with mouse boxes at the top and bottom positions of each rack that contains mouse phantoms. Every position within a rack that is not occupied by a mouse must contain a mouse phantom. The phantoms provide a uniform scattering environment for the mice that are being irradiated. The rack is centered on the table. The remaining racks must be lined up on both sides of the center rack, parallel to the source elevators.

For the one and two single-load mouse boxes, the positions along one side of the boxes are filled as described above, either with mice or phantoms, and centered on the white support box. For the two-box array, the boxes are stacked.

Physical Considerations

The γ-ray field of the cobalt facility is significantly more uniform in the horizontal position than in the vertical position. If field uniformity of better than 5% is desired, it is recommended that three full racks be used. Fill the central position of each rack, working up and down in the racks. Completely fill horizontal rows across the three racks before filling the vertical rows.

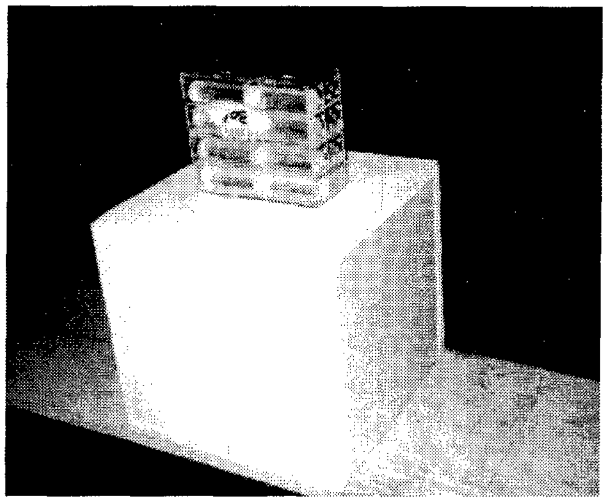

Fig. 15. Two single-load mouse boxes on white support box.

It is very important to use phantoms as prescribed above. The phantoms provide uniform scattering throughout the array and providing a more uniform dose to the mice. If the phantom racks are not used or the phantoms are not used in the top and bottom positions in the rack, the dose to the mice on the sides, top, and bottom cannot be considered to be the same as the dose to the mice in the characterized portion of the array. If the investigator neglects to use phantoms to fill any gaps within the characterized portion of the array (when fewer than the maximum number of mice that each rack can hold are irradiated), the dose throughout the array cannot be considered to be well-characterized.

If there is going to be any deviation from the approved array, the deviation must be approved by RSDD to ensure that all physically significant issues are addressed and that the investigator gets the desired results.

DCFs and Field Uniformities

Array	DCF	Field uniformity	
		Vertical	Horizontal
1 full rack	0.99	7%	1%
1 single-load rack	1.01	5%	1%
2 full racks	0.99	5%	1%
2 single-load racks	1.03	5%	1%
3 full racks	0.97	5%	1%
1 single-load mouse box on white support box	1.00	5%	1%
2 single-load mouse boxes on white support box	1.00	5%	1%

Primate Array

Approved Array

Chaired primate, bilateral exposure (fig. 16)

Description

A wood box, open on one side, is centered on the boards over the cobalt pool. Lead bricks are placed in two stacks of 6 bricks each on the two sides of the box that face the source elevators, a total of 12 bricks on each side (24 bricks in the array). A chaired primate is placed in the box, facing the south source elevator. An acrylic cover is placed over the primate. See figure 16.

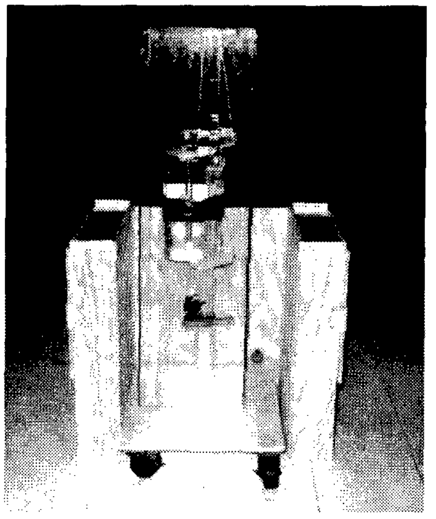

Fig. 16. Chaired primate, bilateral exposure.

Physical Considerations

The acrylic cover shields the primate from electrons and ensures that the dose received is due solely to γ rays. Lead bricks are placed on both sides of the seat of the primate chair to shield the lower body of the primate.

If there is going to be any deviation from the approved array, the deviation must be approved by RSDD to ensure that all physically significant issues are addressed and that the investigator gets the desired results.

DCF and Field Uniformity

The DCF for this array is dependent on the circumference of the primate at its midsection and is calculated according to the following equation:

$$DCF = 1.01 - 0.39x$$

where x is the circumference of the primate in meters. Currently, field uniformity is not of primary concern. The doses to various organs, however, are of concern to investigators. If uniformity becomes an issue, it will be addressed when the need arises.

Rat Arrays

Approved Arrays (not shown)

Two full racks (five holders each), whole-body, bilateral exposure

One full rack (four holders), body-shielded, bilateral exposure

One full rack (four holders), head-shielded, bilateral exposure

Two full racks (five holders each), whole-body, bilateral exposure. Two racks with five rat holders each are placed across the field so that the entire array is centered in the field. Positions without rats must contain rat phantoms.

One full rack (four holders), body-shielded, bilateral exposure. One rack with four rat holders is centered in the field. One or two rats may be placed in the rack. Positions without rats must contain rat phantoms. Two stacks of lead bricks are placed on both sides of the array so that the rat is shielded from the shoulder back along the length of its body. A stack of lead bricks is 8 bricks high for a total of 32 bricks in the array.

One full rack (four holders), head-shielded, bilateral exposure. One rack with four rat holders is centered in the field. One or two rats may be placed in the rack. Positions without rats must contain rat phantoms. A stack of lead bricks is placed on both sides of the array so that the rat is shielded from the shoulder forward along the length of its head. A stack of lead bricks is 8 bricks high for a total of 16 bricks in the array.

Physical Considerations

The γ-ray field at the cobalt facility is significantly more uniform in the horizontal position than in the vertical position. For the best possible field uniformity, fill the positions in the racks so the central portion of each array is always filled, and then fill up and down in the racks. Always fill a complete horizontal row across the array before filling positions in the vertical rows.

Phantoms must be used as prescribed above to provide uniform scattering throughout the array—a more uniform dose to the rats. If phantoms are not used, the dose to the rats cannot be the same as the dose to the rats in the characterized array. If the investigator neglects to use phantoms to fill any gaps in the characterized portion of the array (when fewer than the maximum number of rats that each rack can hold are irradiated), the dose

DCFs and Field Uniformities

Array	DCF	Field uniformity	
		Vertical	Horizontal
Two full racks (five holders each), whole-body, bilateral exposure	0.95	1%	1%
One full rack (four holders), body-shielded, bilateral exposure	0.97	2%	NA
One full rack (four holders), head-shielded, bilateral exposure	0.94	2%	NA
Stack of two rats, whole-body, bilateral exposure	0.85	7%	NA

throughout the array cannot be considered to be well-characterized.

If there is going to be any deviation from the approved arrays, the deviation must be approved by RSDD to ensure that all physically significant issues are addressed and that the investigator gets the desired results.

Spore and Chemical Arrays

Approved Arrays

Two-level rack, bottom half only (fig. 17)

Two-level rack, both halves used (fig. 18)

Two-level rack, bottom half only. The bottom half of the two-level rack is placed on the white support box and centered. It is filled with tubes, with the two end positions as phantoms. A phantom is a tube filled with tissue-equivalent (TE) plastic or water to a level equal to the level of solution in the other tubes being irradiated. If fewer than the maximum possible number of sample tubes is to be irradiated, fill in any open positions with phantoms. Irradiate the array.

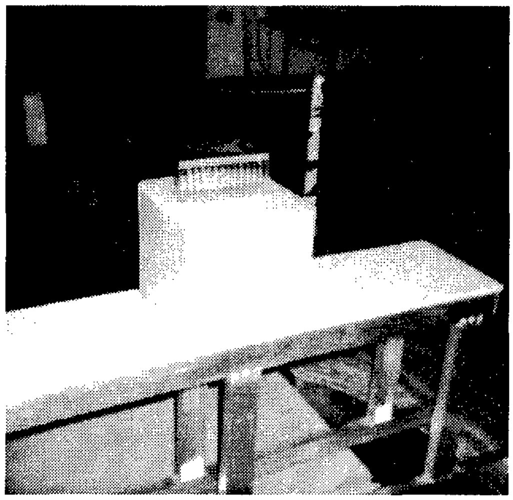

Fig. 17. Spores/chemicals, dual rack, bottom half only.

Two-level rack, both halves used. Both halves of the two-level rack are filled, placed on the white support box, and centered. The tubes on both ends of both levels must be phantoms. Further, if fewer than the maximum possible number of tubes is to be irradiated, then any positions that are not filled with sample tubes must also be filled with phantoms. Phantoms are tubes filled with TE plastic or water to a level equal to the level of solution being irradiated in the sample tubes. Irradiate the array.

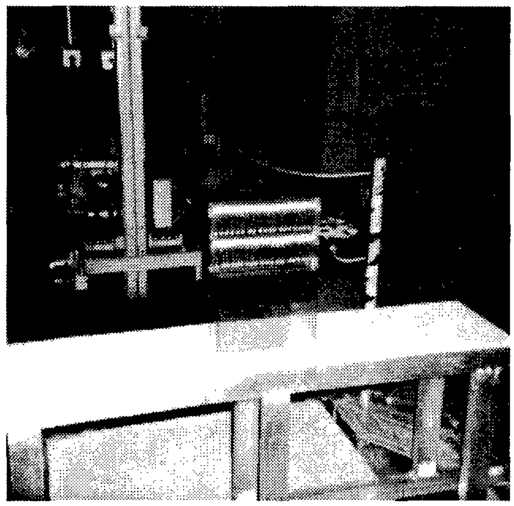

Fig. 18. Spores/chemicals, dual rack, both halves.

Physical Considerations

CPE concerns have been addressed in the design of the array itself. The racks have been designed and built so that the walls provide the proper amount of material to ensure that CPE exists.

It is very important that phantoms be used as prescribed above. The phantoms provide uniform scattering and a more uniform dose throughout the array. If the end positions are not filled with phantoms, the dose to the sample tube on each end cannot be considered to be the same as the dose to the sample tubes in the well-characterized portion of the array. Further, if gaps in the array are not filled with phantoms, then the dose within the array itself cannot be considered to be well-characterized.

If there is going to be any deviation from the approved arrays, the deviation must be approved by RSDD to ensure that all physically significant issues are addressed and that the investigator gets the desired results.

DCFs and Field Uniformities

Array	DCF	Field uniformity
Spores/chemicals		
Two-level rack, bottom level	0.94	4%
Two-level rack, both levels	0.95	4%

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This report describes current arrays used to hold and position objects for irradiation in the AFRRI ^{60}Co irradiation facility. The arrays are specifically designed for use with nonhuman primates, canines, ferrets, guinea pigs, rats, mice, spores, cells, and chemicals. Dosimetry characteristics, such as dose conversion factors and field uniformity, have been determined for each array.

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